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Status of biogas technologies and policies in South Korea

Yong-Sung Kim[a,*], Young-Man Yoon[b], Chang-Hyun Kim[b], Jens Giersdorf[a]

[a] Deutsches BiomasseForschungsZentrum (DBFZ), Torgauer Straße 116, 04347 Leipzig, Germany
[b] Biogas Research Center, Hankyong National University, Jungang-ro 167, 456-749 Anseongsi, Gyeonggido, South Korea

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ABSTRACT

To date, there are about 49 biogas plants in South Korea that are generally recognized as economically and technically unsuccessful due to lack of knowhow, deficient technologies and policies. There is a need to analyze the status of biogas technology and policy in South Korea from the point of view of an external biogas expert, since biogas technology in South Korea has not yet been analyzed by foreign biogas experts so far. For analyzing site investigation, literature research and interviews are performed. It was found that there are several lacks of conceptual design of biogas technology, such as plant dimension, energy balance, operation knowhow. Technical and financial support for the development of biogas technology was insufficient so far. There are some policies to support biogas technologies, however financial support from different ministries seemed not to have been used efficiently. Some policies are planned excessively so that they cannot be realized on time. Based on the general policy called "Green Growth", the Korean government plans to establish a biogas market in South Korea in order to recover energy from organic waste. For this purpose, R&D efforts should be intensified for consulting and education in national and international networks for the transfer of knowhow and technologies. Definition of the existing restrictions on the development of biogas technology is required. By developing a biogas roadmap, the creation of a biogas market could be promoted efficiently in South Korea.

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Contents

* Corresponding author. Tel.: +49 0341 2434 570; fax: +49 0341 2434 133.
E-mail address: yong-sung.kim@dbfz.de (Y.-S. Kim).

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1. Introduction

So far approximately 50–70% of organic waste such as food waste, animal manure or sewage sludge in South Korea is dumped into the ocean [1]. From 2012 on, this action will be banned for animal manure and from 2013 on, for food waste. Recently the Korean government has announced the national new vision of "Low Carbon, Green Growth" and has established various policies on the renewable energies, which are creating favorable conditions for the development of biogas technologies [2]. To date, there are about 49 biogas plants in South Korea that are generally recognized as economical and technical unsuccessfulness because the existing biogas plants are not running well or produce less amount of biogas than expected or operation costs are very high. Therefore there is a need to analyze the status of biogas technologies and policies in South Korea, especially from the point of view of an external expert. Furthermore, measures for development of biogas technologies should be suggested. With this motivation, an agreement for R&D cooperation in biogas technologies between Deutsches BiomasseForschungsZentrum in Leipzig in Germany and Biogas Research Center in Anseongsi in South Korea was signed in January 2011. Mutual visits, a two-month research stay and a joint biogas expert workshop were funded by the International Bureau of Federal Ministry of Education and Research (BMBF) in Germany and the National Research Foundation in South Korea.

1.1. General, economic information of Republic of South Korea

The Republic of South Korea is located in the eastern part of Asia. Its total territory area is 99,392 km^2. The population is about 50 million. On the one hand, South Korea has been developing rapidly since after the Second World War and the Korean War in 1953 The Korean economy market is ranked at 14th in the world by nominal GDP. South Korea is identified as one of the G20 major economies and the 6th largest exporter and 10th largest importer in the world. South Korea is the 5th largest nuclear power producer, which fulfills 45% of electricity demands in South Korea. South Korea is the world's 10th largest energy consumer and the world's largest share of LPG consumption representing 22%. South Korea completed a free trade agreement (FTA) with the EU in 2010. On the other hand, dependency on overseas energy sources is 97%. Oil import corresponds to 27% of the total income. South Korea is the world's 9th largest emitter of carbon dioxide. South Korea is facing energy problems as well as waste problems at the moment.[1]

1.2. Korean policy of renewable energy

The current Korean president, Lee Myung bak, has presented a national vision of 'Low Carbon Green Growth' as the core republic's new vision, promulgated on the 60th anniversary of the foundation of the nation in 2008 [3]. It consists of 9 key projects which aim at securing an environmentally friendly energy, and increasing energy independency. South Korea is striving to reach 100% of energy independency by 2050. One way to achieve this goal is by converting waste to energy. The total amount of waste produced in South Korea in 2008 was 0.38 million t/day. 81.6% of the total waste was recycled, 10.8% dumped in landfills, 5.6% incinerated and 2% dumped into ocean [1]. From the point of view of primary energy supply in South Korea, renewable energy's portion is still very small indicating 1.9% to the total primary energy supply in South Korea in 2007; it is shown in Fig. 1 [4]. 68% of the primary energy is supplied by coal and petroleum. So this dependency

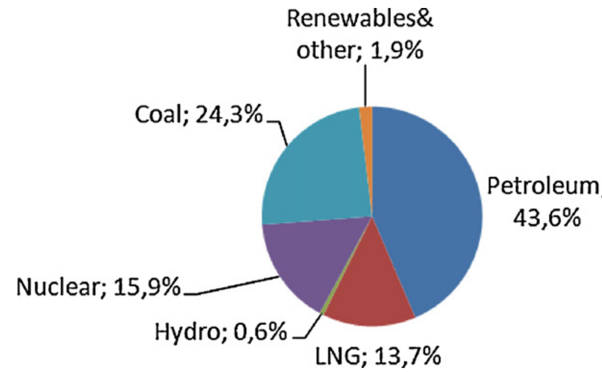

Fig. 1. Status of primary energy supply in South Korea in 2007.

on fossil energy should be decreased while increasing renewable energy aimed at 11% in 2030. One of the key factors for achievement of this aim is recycling of organic waste. 75% of the waste portion of renewable energy in 2007 should be reduced to 33.4%, while 6% of the biomass portion in 2007 should be increased to 31% by 2030 [1]. Bio energy can be produced from e.g. forest residues, agricultural residues, sewage sludge, animal manure, food waste, industrial organic waste and the dedicated energy crops and used as an energy carrier in form of e.g. bio methane, bio diesel, bio ethanol, bio hydrogen pellets, briquettes. The focus of this study was biogas production from bio waste, especially food waste, animal manure and agricultural residues which are readily available for biogas production.

1.3. Status of residue and biogas potential

The expected amount of food waste, animal manure, and sewage sludge in 2010 is about 3.9 million t/year, 58 million t/year, and 2.3 million t/year, respectively [5]. Regarding the portion of organic matter in the waste, only food waste and animal manure are considered in this study, although the reduction of the amount of sewage sludge is very important. Biogas potential estimated from this food waste and animal manure is about 0.7 billion m^3 of biogas per year, which covers around 0.34% of the total electricity demand corresponding to approximately 1300 GWh per year or 65% of total CNG demand by approximately 18,000 Buses in 2008 [6]. Another interesting residue is agricultural residues such as rice straw, husks, corn stalk. In Fig. 2 [7], 75% of agricultural residues come from rice cultivation, including rice straw and rice husks, which amounted to

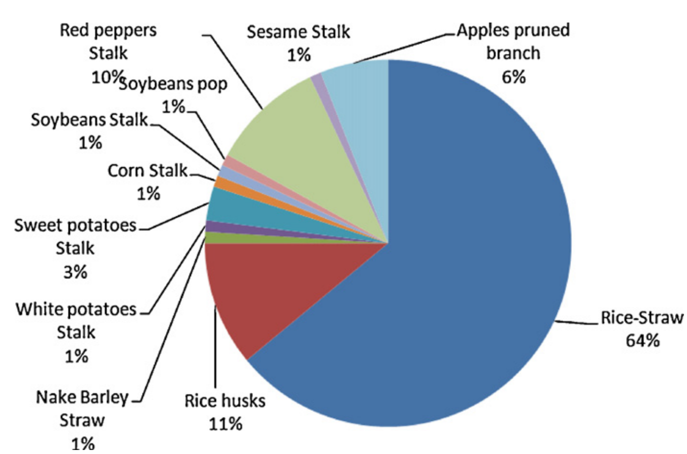

Fig. 2. Agricultural residue in 2008.

[1] http://en.wikipedia.org/wiki/South_Korea, this page was last modified on 28 August 2011 at 23:41.

Table 1
The Korean companies that are in cooperation with foreign companies.

Name	Products	Size	Cooperation	Contact
Seohee	Dranco plant	Big	Dranco, Belgium	http://www.seohee.co.kr
Ecoenergyholdings	Biogas upgrading	Small	Swedish Biogas International	http://www.ecoenergyholdings.com/
Leebcor	Plant	Small	Weltec	http://leebcor.co.kr
Scandinavian Biogas Korea	Plant	Small	Scandinavian Biogas	http://www.scandinavianbiogas.se/index.php
Neopurple	Plant	Small	Krieg&Fisher	http://www.neopurple.co.kr/
Hydrogenpower	Plant	Small	Frauenhofer, PlanET	http://www.hydrogenpower.kr/index.html
Junglim	Plant	Small	Lipp	http://www.ststank.co.kr/
Unison hightec	Plant	Small	Suma, elektro Hagl	http://www.unisonhitech.co.kr/

7.7 million t/year in 2008. The share of paddy to the total farmland is about 70% representing 927,995 ha [7]. In general, field residues left in the field after harvesting, like stalks, are used as materials to increase efficiency of irrigation and control of erosion. Process residues left after processing of crops, like husks, are used as fodder, soil amendment, and fertilizer. Another use of these residues can be biogas production. The biogas process can recover not only energy from these residues but also nutrients. The nutrient remnant from the energy production can also be used as fertilizer since it contains valuable minerals such as nitrogen, phosphate and potassium.

1.4. Current state of biogas production

There are 49 biogas plants in 2010. Among them, 2 plants are fed by food waste, 5 plants by food wastewater, 9 plants by livestock manure, 13 plants by mixture of substrates, and 20 plants by sewage sludge [2]. The share of electricity from biogas process to the renewable energy is 0.08% indicating 3363 MWh in 2008 [8]. At the moment, biogas production – and biogas use rate is relatively very low despite its high potential.

2. Methodology

For analysis of the status of biogas technologies and policies, the author[2] visited the Biogas Research Center in Anseongsi in South Korea and a research stay was realized from February to March 2011. Relevant literatures and governmental reports prepared by the Biogas Research Center were investigated. Based on this theoretical research, biogas plants to be visited were classified by substrate use such as plants fed by animal manure, by food waste, by food waste and sewage sludge, and finally by food waste, sewage sludge and animal manure. While visiting the plants, process data was collected through interviews and the plant information flyer. Additionally selected Korean biogas experts were interviewed about the status of biogas technology in South Korea. The author[1] visited the following experts: Professor Chang Hyun Kim, Doctor Youngman Yoon of Biogas Research Center, Joon Pyo Lee of KIER (Korean Institute of Energy Research), and Professor Ho Kang of Chungnam National University. The collected data was analyzed and some measures as demand for R&D were suggested with aid of the German standard biogas technology books [9,10].[3]

For systematical analysis of the existing restrictions on development of biogas technology in South Korea, 9 aspects such as geography, hygienic management, food security, nutrient circulation, technology, society and environment, economy, regulation and R&D were considered. They are reflected in Section 3.7.

Additionally, for suggesting appropriate measures for a biogas roadmap, the interesting entities of biogas technology are grouped into 7 categories such as substrate, economy, technology, administration, R&D, sustainability and policy. Under each category, general critical points for biogas road mapping are briefly introduced. They are reflected in Section 3.8.

3. Results and discussions

3.1. Status of biogas technologies in South Korea

There are several biogas plants functioning as pilot plants for investigation, and some plants for commercialization in South Korea. Approximately 95% of biogas plants use a wet fermentation system. Usual substrates are animal manure, food waste or sewage sludge. Dedicated energy crops do not come to consideration at the moment since Korea has 27% of food self-sustainment [7]. In Table 1, some Korean biogas companies are cooperating with foreign companies e.g. from Germany, Denmark, Sweden, and Japan. Core components like Combined Heat and Power Plant (CHP), stirrer and gas bags etc. are imported from those countries. Direct import of foreign technologies in South Korea has caused many problems, such as after service problems, high cost of techniques and time for transport.

Table 2 shows the biogas plants visited. Each plant was introduced briefly under several categories such as plant location, type, substrate, volatile solid (VS) degradation, mean content of CH_4, biogas production, capacity, and biogas use.

Hankyong pilot plant was built in January 2008 with support of Hankyong National University, the city of Anseong, and the province of Gyeonggi. The plant is running well. At the plant, various investigations such as the optimization of process, the development of gas upgrading technique, and the development of gas bags have been conducted.

Asan plant was built in 2008 by Daewoo Institute of Construction Technology. This institute has investigated anaerobic digester since 1990. Its technique is the two phase anaerobic system, in which USAB is served for the methanization stage. The current focus of investigation is the combination of dry fermentation, integrating PFR to the existing two phase system.

Gochang plant was built in 2010 by Unison hightec. This plant is very similar to the German farm biogas plant. Core elements of the plant like CHP, stirrer, gas bag are imported from Germany. This plant shows stable process. However, the amount of biogas produced is relatively low due to the characteristic of the substrate.

Dongdaemoon plant was built in 2010 by Seohee construction. Its technique is DRANCO. The plant is located in the city center. Due to odor problems, the plant is built under ground and has two big ventilators (350 kW) to suck odors, and two burning systems of exhaust gas (RTO), including a chemical cleaning system which causes high costs of construction and maintenance.

Seonam sewage sludge treatment plant has a standard treatment technique of activated sludge. Near to this plant, there is the Seonam biogas fuel station. This station was built by support of Ecoenergyholdings, Swedish Biogas International and Seonam treatment plant in Seoul in 2009. The gas upgrading technique is

[2] Yong-Sung Kim.
[3] It was used as a questionnaire for analyzing biogas plants.

Table 2
The selected biogas plants.

Plant	Anseong Gyeonggi Hankyong Pilot	Asan Chungnam Daewoo Pilot	Gochang Jeonbuk Nonghyup BGP	Dongdaemoo n Seoul Seohee BGP	Gangseo Seoul Seonam WWTP	Ulsan Gyeongnam Yonghyun WWTP
Type	PFR	USAB, Two phase system	CSTR	DRANCO	Waste water treatment plant	Septic tank mixed by air pressure
Substrate	Animal manure 4.2 t/d (TS 3.5%) + food waste 1.8 t/d (TS 13%)	Sewage sludge 25 t/d + food waste 25 t/d + animal manure 50 t/d	Swine manure 50 t/d (COD 12,000 mg/l)	Food waste 98 t/d	Waste water 1.5 million t/d	Food waste 180 t/d + sewage sludge 320 t/d
VS degradation	63%	61.7%	85% (Goal)			
Mean content of CH_4 biogas production	67%, 340 m^3/d	74%	70%	60%, 9000 m^3/d	50,000–60,000 m^3/d	60%, 27,500 m^3/d (Goal)
Capacity, use of biogas	720 kWh_{el}/d	1500 kWh_{el}/d	2080 kWh_{el}/d (Goal)	19,200 kWh_{el}/d	4800 m^3/d upgraded	Biogas sold to industry

water scrubber imported from Sweden. The upgraded biomethane is being sold at the price of 597 KRW[4]/m^3.

Ulsan plant was built in 2010 by Scandinavian Biogas Korea as a financing form of Build Operate Transfer (BOT). This biogas plant is in combination with the sewage sludge treatment plant. Biogas is cleaned and sold to industries located within close proximity at the price of 600–700 KRW/m^3. To date they focus on the development of biogas upgrading technology to increase profitability.

3.2. Demand for R&D of biogas technologies

In South Korea, biogas technology was introduced in early 1970s for cooking in rural areas and then for the treatment of animal manure in 1990s. But these trials did not succeed. Coming in 2000, biogas technology started getting attention again. Afterwards it has been developed mostly by applying the technology of waste water treatment such as technology of controlling, technical equipment, and construction, which are regarded as successful technologies. But this anaerobic technology of waste water treatment plant aims at treatment of organic waste, not the production of biogas, as a result low efficiency of the plant was shown regarding biogas production. Additionally some following problems could be found.

In some biogas plants, lack of basic concepts of biogas technologies during planning, such as dimension of plant, substrate management, selection of technologies, selection of plant site, nutrient management, energy use, mass balance, plant security and control, economical profit, operation and maintenance could be seen. Therefore many economic losses and technical failures could be founded [6].

Table 3 presents some problems of selected biogas plants.

So, during planning of a biogas plant, the efficiency of energy, biogas production, and technologies should be more concerned and improved. Especially conversion technology from biogas to energy e.g. CHP and its controlling knowhow should be advanced as well as technology for the energy use.

Another reason of those problems can be lack of biogas roadmap for policy maker and stake holders. It was shown than many different industries lacking knowhow of biogas technologies built different types of biogas plants. In this case, roadmap of biogas technologies and policies in the long term should be probably established to alleviate the policy maker and stakeholder to make decisions effectively.

Korean biogas market is not formed. In every chain link of the product life cycle of biogas technologies i.e. from supply and transport of substrate through transport and use of digestate, appropriate technologies should be developed for the creation of biogas market. Thereby standardization and modulation of techniques could help safeguard economical profit. The governmental subsidy should support industries to develop such technologies.

For the first step, building up some localized and optimized pilot, and demonstration plants is necessary to evaluate mass flow and costs.

To ensure a successful deployment of biogas technologies, intensive R&D efforts for consulting and education are required. Creation and maintaining of national and international networks for transfer of knowhow are inevitable.

3.3. Status of policy in South Korea

3.3.1. General policy

"Low Carbon Green Growth" strategy in South Korea. A new national vision – "Low Carbon Green Growth" – to be realized within the next 60 years, was announced on August 15th 2008. The four elements of green growth are green technology as a new growth engine, green energy paradigm, improvement in quality of life and contribution to the global community. The 'Green New Deal' was announced in January 2009, and consists of 9 key projects, and supporting projects focused on job creation, as well as building the foundation for a low carbon economy transition, represented in Table 4 [11].

This is basic framework of the Korean green growth policy. The main part of this policy is the 4 major river revitalization, showing about 29%. This policy seems to focus on public works concerning the projects such as 4 major river vitalization, green transportation, water resource catchment, green home and green school. Timeline for this policy is until 2012, which could mean low probability of realization. The portion for waste resource reuse is about 1.86%. It is difficult to know from this table how many portion of support for renewable energy is. For green car and clean energy it is planned to support with 4.1%. The support portion for biogas technology cannot be noticed from this table, but it can be supposed to be relatively very small.

Table 5 is an investment plan focusing on renewable energy with timeline from 2010 to 2030 [12].

Increase of investment at solar energy and waste with time is noticeable. From this table, it can be seen that Korean policy maker places more weight on solar energy than others (44.3% including photovoltaic) in 2030. The portion of bio energy is 11.9% in 2010 and 12.2% in 2030. The fraction of energy recovery from waste is a relatively higher part representing 17.4% in 2010. There is a portion for development of technologies, which are decreased with time dramatically i.e. from 18.1% in 2010 to 5.7% in 2030. Biogas is planned to be supported at the rate of 2.9% in 2010 and 4.1% in 2030.

[4] 1 Euro is 1559 KRW, 30th of August 2011.

Table 3
Problems of selected biogas plants.

Substrate management	Some plants are fed just by manure, which means low profitability because of its lower organic content. Some plants have only food waste as substrate, which can induce instability of process biology.
Dimension of plant	Some plants have a reception tank which is dimensioned too small, which cannot guarantee the stable feeding of substrate in case of fluctuation of substrate transport. Some plants have a digestate storage tank or gas bag oversized, which means higher cost of investment.
Selection of technology	Some plants have CHP (capacity oversized), which is not suitable to the amount of biogas produced. Some plants do not have flare which is important for plant security or protection of the environment in case of e.g. breakdown of CHP. Some plants have stirrer or pump imported from abroad, which cause more cost due to transport in case of maintenance. Some plants fed by bio waste like food waste or carcass do not have hygienic facility, which is important to avoid hygienical problems.
Selection of plant site	Some plants are located in unsuitable positions like in city centers or villages, where there is a transport problem. A plant in a city may cause odor problems.
Energy use	Biogas from some waste water treatment plants is not used and released into the air. Some plants have relatively high energy consumption for process, which means less selling the energy. Some plants have low control technology for energy use. Some plants have no concept for heat use.
Mass balance	Some plants do not assess mass balance, which is to evaluate the efficiency of plant.

Table 4
"Low Carbon Green Growth" strategy [11].

Project name		Budget (billion KRW)			Job creation (# of jobs)		
		2009	2012	Total	2009	2012	Total
Total		4363	45,687	50,049	93,360	863,060	956,420
Key projects	4 major river revitalization	488	13,990	14,478	7000	192,960	199,960
	Green transportation	1835	7819	9654	25,042	113,025	138,067
	Integrated territory management	25	347	372	816	2304	3120
	Water resource catchment	185	758	942	3063	13,069	16,132
	Green car and clean energy	321	1732	2053	1643	12,705	14,348
	Waste resource reuse	51	879	930	2377	13,819	16,196
	Forestry	313	2104	2417	22,498	148,204	170,702
	Green home, green school	–	8050	8050	–	133,630	133,630
	Ecological river	5	479	484	393	10,396	10,789
Supporting projects		1140	9530	10,670	30,528	262,038	141,639

Table 5
Investment plan at renewable energy from government and private companies [12].

	(10^8 KRW)			
	2010	2015	2020	2030
Solar	440	2381	6964	19,165
Thermal (water heating)	440	1697	4699	16,168
Electrical (heat engine)	–	685	2265	2996
Photovoltaic	8644	5546	6975	9567
Wind	3073	4061	3686	3174
Hydro (small)	345	323	308	562
Bio	3955	3542	5870	7892
Cellulosic	2489	910	3177	4748
Biodiesel	85	113	295	354
Bioethanol	253	107	101	160
Biogas	969	2266	2159	2656
LFG	159	146	138	64
Geothermal	2509	5030	5669	9937
Ocean	2401	5316	1815	–
Waste	5776	9942	12,739	10,763
RDF	2690	6907	9739	7828
Incineration heat	3086	3036	3000	2936
Subtotal	27,143	36,142	44,028	61,151
Development of techniques	6000	9000	6500	3700
Total	33,143	45,142	50,528	64,851

3.3.2. Policy of the Ministry for Food, Agriculture, Forestry and Fisheries (MIFAFF)

The Ministry for Food, Agriculture, Forestry and Fisheries (MIFAFF) has planned to build three biogas plants in 2010, as well as in 2011, and four plants in 2012, 5 plants in 2013 and 85 plants during 2014–2020, i.e. a total of 100 biogas plants for the digestion of animal manure until 2020. Each biogas plant can be funded by different financiers i.e. by government at a share of 30%, local government at the share of 30%, credit at the share of 20%, and private investment at the share of 20% of the total budget of investment; it is shown in Table 6 [7].

3.3.3. Policy of Ministry of Environment (ME)

In cooperation with six other ministries, the Ministry of Environment intends to build 600 eco villages by 2020 in order to reach 40% energy independency of a village through the use of waste, biomass, solar, wind and small hydro energy. There are four different models of energy villages, depending on the region e.g. urban, rural, mountain area and a combination of rural and urban areas. However realization of this policy after the planning seems to be skeptical. Additionally, in Table 7 [1], the Ministry of Environment plans to recover energy from wastes, which are normally dumped into the ocean, in the form of biogas and RDF (Refuse Derived Fuel). 24% of waste should be recovered by biogas plants by 2013.

Table 6
Funding plan for building biogas plant [7].

		(Billion KRW)				
		2010	2011	2012	2013	2014–2020
Number of plants		3	3	4	5	85
Budget	Total	18	18	24	30	510
	Government Supply (30%)	5.4	5.4	7.2	9	153
	Credit (20%)	3.6	3.6	4.8	6	102
	Local government Supply (30%)	5.4	5.4	7.2	9	153
	Private investment (20%)	3.6	3.6	4.8	6	102

It can be seen from this table that the Ministry of Environment plans to build biogas plants to recover energy from liquid food waste (food waste water) and animal waste. In case of fermentation of animal waste, this support policy can be overlapped with the policy of MIFAFF.

3.3.4. Policy of Ministry of Knowledge and Economy (MKE)

For supporting the policy of Low Carbon Green Growth, the Ministry of Knowledge and Economy made some promotion strategies such as Renewable Portfolio Standard (RPS), green accreditation, and renewable project. RPS policy is coming into force from 2012 meaning that the plants producing more than 5 MW electricity should have a share of 2% from renewable energy source. The share rate should be increased up to 10% by 2020. The policy of green accreditation means that the state will accredit green technologies and businesses to give financial and fiscal benefits as an incentive for private industries who participate in the renewable energy market. There is a financial support program too. With the name of renewable project, MKE gives financial support to build two biogas plants every year [13,14].

3.4. Demand for R&D of policy

With the green growth policy as a national vision, government gives financial support in large scale for the recovery of waste. As a result, about 49 plants are built and more plants are going to be built. However, financial support for the development of biogas technologies by different ministries seemed not to have been used efficiently because the most existing plants are recognized as not profitable and not technical efficient, while about 500 billion KRW were invested for those plants ministries so far. Some policies are planned excessively so that they cannot be realized on time.

Policies and financial supports should be consistent. For this purpose, road mapping of biogas technology and policy is probably necessary to support the policy maker and stakeholder. To enlarge participation of industries, legal supports should be provided as well.

Regarding reduction of CO_2 emission, compensation incentive like Erneuerbare Energien Gesetz (EEG) should be upgraded.

An important point in the policy is the concept change from waste treatment to energy recovery from waste. In this concept change, biogas technology should be improved for increasing the efficiency of biogas production.

Furthermore substrate spectrum should be extended for increasing biogas production, because amount of bio waste cannot cover the demand for energy (see Section 1.2, 1.9% of renewable energy to the total primary energy supply). So, another renewable biomass like agricultural byproduct, industrial organic waste should be involved in substrate variables. Especially energy crops should be concerned as substrate alternatives for biogas production in terms of sustainable energy source instead of fossil fuel.

3.5. Economic support framework

There is a policy mechanism designed to encourage the adoption of renewable energy. However this is very restricted, e.g. the state gives an incentive to the plant operator for selling electricity from biogas, if this plant was supported to be built for less than 60% of investment by state. The amount of incentive is also insignificant, about 72.73–85.71 KRW/kWh [15]. The normal price of electricity is 110 KRW to 130 KRW/kWh depending on the season, time and purpose. To date, a main income source is gate fee representing 60,000–100,000 KRW/t for food waste and 12,000–20,000 KRW/t for animal waste. Some plants are selling biogas as fuel. In this case, the price of biogas is between 550 and 700 KRW/m^3 paid by consumer.

Table 7
Recovery of waste [1].

Middle area	Recovery of energy in landfill station Organic waste: Sewage sludge 1000 t/d → Solid fuel Food waste 1000 t/d → Biogas
East area	Decision of plant site Organic waste: Liquid food waste 120 t/d → Biogas Animal waste 80 t/d → Solid fuel
South West area	Decision of plant site Organic waste: Liquid food waste 320 t/d → Biogas Animal waste 260 t/d → Biogas
South East area	Decision of plant site Organic waste: Liquid food waste 380 t/d → Biogas Animal waste 220 t/d → Biogas
Combustible materials	Public part 1.75 million t/a, private part 0.1 million t/a RDF producing facilities (20): 4 Town and 16 plants RDF using facilities (10): 4 Town and 6 plants
Organic materials	Public part 1.63 million t/a, private part 0.32 million t/a Refuse-Derived fuel (RDF) from sludge (4): 1 Town and 3 plants Biogas from liquid food waste (11): 4 Towns and 7 plants Biogas from co-digestion (12): 3 Towns and 9 plants

Table 8
Regulation of fertilizer for commercial transaction [16].

Digestate	Compost	Liquid fertilizer
Food waste	Yes	No
<30% food waste + 70% animal waste	Yes	Yes
>30% food waste	Yes	No
Sewage sludge	No	No

3.6. Regulation for use of digestate

In Table 8 [16], fertilizer regulation accounts for effect of its components on soil. Digestate with less than 30% of food waste can be used for compost or liquid fertilizer. All agricultural byproducts are available for fertilizer. In contrast, domestic and industrial sewage sludge is not available for fertilizer, since it contains harmful chemicals like heavy metals. However, there is a regulation to allow digestate from sewage in villages to be used as fertilizer, depending on the results of an elemental analysis.

In general, it is very restricted to use digestate as fertilizer. It is related not only to hygienic safety but also to demand of liquid fertilizer, which is usually very low in South Korea. Chemical fertilizer is preferred to be used as fertilizer in South Korea, because it is better manageable in terms of adjustment of nutrient amount in soil and is free from odor problems. At the moment, food waste is favored to be used either as compost or as fodder after appropriate treatment in South Korea, indicating approximately 88% of food waste recycling [17].

The use of liquid fertilizer in paddy has not been investigated systematically.

To find the secure land receiving digestate produced by biogas plant seems to be not easy at the moment in South Korea, but which is one of the important challenges to develop biogas market in South Korea. The potential use of surplus land, such as fallow and reclaimed saline land, as secure land for receiving digestate as fertilizer, is probably to be investigated as a concept of nutrient circulation in a region.

The development of alternative technologies for the use of digestate alongside fertilizer, such as treatment of digestate up to water quality, or treatment which makes burning material like pellets, can be necessary. Furthermore the legal framework should be improved as well.

3.7. Restrictions on development of biogas technology in South Korea

Although there is potential of biogas market in South Korea (described in Sections 1.2 and 1.3 respectively), some restrictions or challenges could be founded as following in Table 9.

Some points could be changeable and improved, but other specific Korean situations like geography or food security could not be changed easily. Concerning these points, there is a need for investigation like feasibility study and customization process. Especially for international cooperation or project, this customization should be accounted.

3.8. Biogas roadmap

To increase the implementation efficiency of biogas policies and technologies, establishment of a biogas roadmap is necessary. For biogas road mapping, some general criteria of biogas technologies are briefly introduced in Table 10.

Is there a need to develop biogas technologies or a biogas market in South Korea? This need should be acknowledged by every participant of all interested groups; it is shown in Fig. 3. Needs should be identified and arranged in different critical categories.

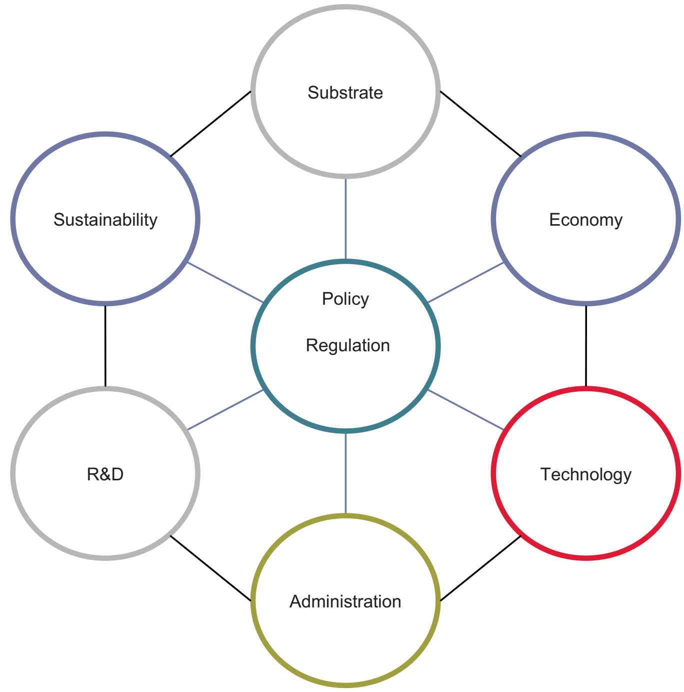

Fig. 3. Seven entities of technology development (management).

These critical points or requirements should be transformed into the technology oriented drivers which must include a technical target and scope. This target and scope can be enhanced stepwise according to the perspective of a timeline. Simultaneously alternative technology should be identified, including a technical target and also scope. These have to be compared, validated and accepted by all participants. Afterwards it will be involved in any implementation. There should be periodical reviews and identification of update point (need). This need will be used in the planning of a roadmap again.

The close collaboration of entities of technology management can guarantee a success to develop technology and its market.

Biogas technology is a unique technology based on natural biodegradation process, which has a closed system of carbon dioxide and nutrients. In opposition to wind and solar energy, biogas technology can provide energy carrier ‘biogas’ that is storable and transportable. The biogas process uses various organic substrates like food waste, animal manure or energy crops as renewable sources. Biogas technology is a natural process but it has a very large band of technologies. For example, for control of the biogas process, we have to understand micro biology, and for the use of biogas, we need to have CHP to convert biogas to electricity, or upgrading technology to improve the quality of biogas. Biogas technology can be combined to the existing renewable energy system e.g. bio refinery facility like bioethanol production as well as to the existing waste treatment plant. Biogas technology has multivalent possibility of its use, e.g. heat and electricity through CHP on site or satellite-CHP or feeding in the existing gas grid or the upgraded bio methane as fuel [9]. For all, we need appropriate legal frameworks, as well as suitable administrative support. It is also important to notice the aspect (feedback) of plant operator to improve biogas technology further from the point of view of consumers. The impact of biogas technology on the environment, job creation, as well as economy, should be positive and sustainable. Biogas technology is regarded as a green technology to reduce emission of greenhouse gas, and can realize nutrition circulation in soil in local eco energy villages. Biogas technology can be regulated relatively well in application of appropriate technology to inhibit

Table 9
Restriction on development of biogas technologies in South Korea.

Geography	Arable land 19%, forest and woodland 65% → problem of transport; river and lake 10%; monsoonal region, typhoon, flooding, Seismic activity; long winter up to −10°C
Hygienic management	Foot and Mouth disease, 3.2 million of livestock killed this year, 3 million (95%) are swine, which are 30% of total swine; restricted access to livestock farm; forbidden to access to livestock manure; restriction of manure transport during the outbreak of animal disease; no hygienic regulation
Food security	27% of food self-sustainment including fodder (51% exclusive fodder); rice self-providing is more than 100% (see also Section 3.3), rice consumption per person is 76 kg/year; no surplus land for energy crops considered
Nutrient circulation	Import of 75% of fodder feedstock, 15,242,000 t in 2007; the largest consumption of fertilizer in the world, 13.1 kg/ha, most of all chemical fertilizer; nutrients enough in soil from abroad; problem of use of digestate as fertilizer
Technology	Construction cost is relatively high, e.g. because of expensive techniques to avoid odor problems, to fulfill the strict regulation; most core components e.g. CHP, stirrer, gas bag are imported, maintaining problem; biogas market is not yet formed; many technic components should be developed.
Society and environment	Odor and noise; digestate and exhaust gas; high salt contents in digestate; animal disease (hygienic point); water contamination; negative preconception; deprecipitation of house price
Economy and policy	Low price of electricity 110 KRW/kWh depending on season, time, and purpose; restricted subsidy; non-consistency of supports and policies between ministries (overlapped polices)
Regulation	Governmental incentive on selling electricity is given just to plants supported by state less than 60% of investment; restricted possibility of use of digestate; restricted possibility of use of biogas. e.a. injection of biogas into arid: strict regulation in general
R&D	Poor field data; lack of standardization of measurement; limited financial support; low level of education and awareness in this area

Table 10
General critical points for biogas road mapping for South Korea.

Substrate	Sewage sludge: use of biogas, installation of anaerobic digesters, treatment of digestate; food waste: treatment by waste water treatment plant or by biogas plant, compost, treatment for fodder; animal manure: treatment by biogas plant, or by public treatment facility; agricultural by-product: use as fodder, fertilizer, treatment by biogas plant
Economy	Investment: government, regional government, energy supplier, bank, farmer, company or house needing heat, industry; electricity: government, energy supplier; heat: e.g. pool, school, hospital, garden, fishery; biogas: fuel station, industry, gas grid
Technology	Substrate: cultivation, harvest, collection, transport, storage; energy production: feeding, mixing, digester, transport, control, measuring, maintaining, safety; energy use: CHP, flare, boiler, gas cleaning, gas upgrading, gas and heat transport, injection; distribution of digestate: dewatering, treatment (conditioning, pellet), transport, distribution
Administration	Simplification: application, permission, control; standardization: utilization, adoption, dissemination; biogas regulation: own biogas regulation, compensation payment, energy use
R&D	Industry: development of technology in every chain link of product life cycle, standardization, modularization, development until biogas market occurs, continues and it is profitable; institute and university: technology development, analysis and monitoring, assessment, suggestion
Sustainability	Plant operator: profit, efficiency, convenience; assessment of sustainability on environment: soil, water and air system; impact on society: Job creation etc.; impact on economy
Policy and regulation	Regarding feedback from the biogas fields: seminar, research workshop etc.; organization: exhibition of new technology, various federations, publication, promotion; control: validation, verification; regulation: legal support; investment: financial support; policy improvement

contamination to the existing water and air system. In addition, one should concern general restrictions in developing biogas technology mentioned in Table 9 for the biogas road mapping.

4. Conclusion

South Korea has sufficient infra-structure to ensure the realization of a biogas market. Biogas technology in South Korea focuses rather on treatment of waste than on biogas production at the moment. There is a considerable potential in terms of use of organic waste as substrate. However, there are some changeable and unchangeable restrictions. Diversity of feedstock like energy crops should come into consideration to increase biogas. To date, the biogas market is not formed; therefore a profitable operation of biogas plants is not easy. The improvement of biogas technology and policy is necessary. If biogas technology is optimized, biogas plants can be profitable in South Korea. In the initial stage, many installation costs can incur. However, biogas technology can enable independency of energy, the recycling of organic waste, and nutrient circulation in local energy villages. From the point of view of those, economic benefits can be immense. Regarding development of biogas technology, we have to consider not only profitability, but also independency of energy in a way of green growth. The most important key lies in the awareness of people about it. By means of a biogas roadmap, a biogas market could be realized efficiently. If an optimized biogas system including technology and regulation is created, this system can be easily applied in anywhere, e.g. in North Korea, or in much more northern parts of the peninsula that need a lot of energy and digestate in its country.

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